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SITUATIONAL AWARENESS ASSESSMENT IN AUTONOMOUS VEHICLE TESTING PROFESSIONALS

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Abstract
This work assesses the situational awareness (SA) capabilities of professionals actively involved in the testing of autonomous vehicles (AVs), an area where human supervisors need to manage complex systems that require interpretation and intervention. With the progression of AV technologies, the role of the tester has become more complex as they need to manage supervisory control, real-time decisions, and system overrides simultaneously. The traditional methods of assessing SA have overlooked the cognitive processes and real-time challenges during the work. To fill this gap, our study uses a multimodal neural evaluation framework that combines cognitive and physiological tools (electroencephalography (EEG), eye-tracking, and heart rate variability (HRV)) with behavioral measures of performance and workload evaluation (NASA-TLX). The test subjects were professional AV testers who were performing simulated driving exercises at three levels of task automation: low, medium, and full. The findings demonstrated a decline in awareness of the situation as automation levels increased. While the lower and medium levels of task automation sustained active engagement and accurate situational monitoring, higher automation levels elicited cognitive disengagement and sluggish response times to intervention, as well as reduction in hazard detection—regardless of low subjective workload. EEG data indicated theta and diminished beta rhythms, which are markers of mental fatigue, while eye-tracking showed diminished attention to important dials during high automation. The heart rate variability data pointed to increased stress during ambiguous and failure-prone situations, a phenomenon most pronounced among testers with lower automation levels.
The research confirms that automation does not reduce cognitive load for a user. Rather. it reallocates shifts in attention in a manner that could lower situational awareness. More experienced testers had better attention regulation, gaze consistency, and faster override decision responses which highlights the need for neurocognitive preparedness and training. For these findings, we suggest a real-time situational awareness monitoring and interface adjustment framework which physiologically adapt through biometric data streams to sustain vigilance and trust in the system. This research demonstrates critical industrial relevance, as anthropometric AV test environments need to prioritize attitudinal human factors to sustain cognitive engagement. Incorporating adaptable interfaces, tailored training, and biometric real-time monitoring can enhance tester performance and safety. Ethically, privacy, inclusivity, and data transparency must be prioritized in these frameworks. This research provides a starting point for advanced cognitive integrated AV systems, which achieves the efficiency of automation while providing enduring human situational awareness and responsive automation aids.
Keywords: Situational awareness, AV testing, EEG, eye-tracking, cognitive load, automation, neuroergonomics.

1. INTRODUCTION

The challenges presented by the more complicated systems of autonomous vehicles (AV) has necessitated the deepening level of human situational awareness (SA) in the testing context [1]. AV testing professionals face the unique challenge of assessing systems in contexts that are both fluid and volatile, thus requiring rapid-response situational awareness (SA) and constant scanning of the environment [2]. As automobiles become more autonomous, human testers are required to shift to more autonomous supervision involving command, real-time action, and diagnosis of automated systems failures based on the human situational assessment (SA) [3]. Human AV testers operate in multi-task environments that require monitoring of many data streams, environment, and prepare to and actuate bypass automated functions [2] [4]. This paper

aims to understand the cognitive, perceptual, and physiological situational awareness (SA) demands of AV testing professionals' situational awareness (SA) as a neurocognitive and behavioral construct [6]. This study aims to understand the effects of allocation of attention, workload, and fatigue on situational awareness (SA) using neuropsychology, neuroergonomics and human factors engineering under various testing conditions. As the objectives of the study demand real-time measures of driven EEG, eye tracking, and task performance data, the goal dynamic situational awareness (SA) of operators in AV testing, situational awareness (SA) from a richer real-time perspective.
This research addresses the gap in the model frameworks that fail to incorporate the changing human-automation interplay in the testing of automated vehicles (AVs). We proposed a more biologically and contextually adaptive frameworks. The ultimate goal of the study is to describe the creation of these interface frameworks, instructional systems, and standard operation procedures that would aid in preserving the situational awareness of human operators in the control rooms of AVs technology [10].

1.1 Evolving Role of Human Operators in Autonomous Vehicle Testing

The shift from conventional to automated vehicles has changed the function of human operators from direct controllers to supervisors. Practitioners responsible for the evaluation of automated vehicles engage in oversight of the vehicle's operation, monitoring vehicle functions and sensors, and intervening only when the vehicle is not responding correctly to the environment [8]. This new role requires high level of flexible and sustained attention, and dynamic multi-faceted advanced cognitive functions to identify risks, deviations, or system errors which require proactive mental processing. In contrast to traditional driving, where the perception to action cycles is mostly direct and automatic, AVT requires higher-order interpretive reasoning [9]. Testers are required to simulate the internal system processes and external conditions, such as road traffic and weather. This bipartite role renders the tester highly susceptible to sustained attention fluctuations. Comprehending these risks is vital for AV testing safety and reliability. In this research, we aim to profile testing practitioners' skills AV competencies with safety management systems of situational awareness.

1.2 Importance of Situational Awareness in High-Risk Driving Environments

Situational awareness (SA) is crucial for safety and effectiveness in the testing of autonomous vehicles (AV) in high-stakes environments their safety and effectiveness [3]. The perception of elements in the environment, understanding their meaning, and predicting their future status, are all components of SA. This helps testers preempt possible hazards and system errors. The AV testing environment is particularly unique as testers need to interact with vehicles that can encounter novel situations outside their pre-programmed scenarios. The consequences of diminished awareness in such critical environments with delayed decision making are dire—critical system failures can be unnoticed and unattended to [7].
Moreover, SA is critical in the edge cases which are the focus of the tests—dealing with unpredictable human drivers and abrupt changes to environmental factors [11]. The ability to stay mentally focused, active, assess ever-changing conditions, and execute appropriate responses in a timely manner defines a successful performance. Enhancing SA not only requires training, but also designed interfaces, real-time interfaces, and tracking frameworks. Our study builds on the need to advance the frameworks and real-time tracking interfaces by SA tailored to the demands and complexities of AV environments as a dynamic construct, not static measure [5].

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Situational awareness (SA) has been recognized as a key concept in high-stakes fields like aviation, defense, and more recently, autonomous vehicle (AV) testing [13]. The theoretical backbone of SA derives from Endsley's model, which splits SA into three levels: perception, comprehension, and projection. These levels of SA are important for multi-tasking professionals like in AV testing who monitor, interpret, and forecast complex system behavior and anomalies in real time. AV testing professionals who monitor, interpret, and forecast complex system behavior and anomalies in real time. Traditionally, SA has been evaluated with post-task questionnaires and observational ratings. These methods of evaluation are time-indexed and lack precision and objectivity. To address these issues, neuroergonomic researchers have proposed seeking SA-related cognitive states with EEG, eye-tracking, and heart rate variability (HRV) monitoring. These technologies enable the identification of cognitive fatigue, shift in focus, and cognitive overload well before any decline in performance is observed. While aviation and surgical studies have integrated these technologies, the use of them in AV testing is scarce. This cognitive psychology, human factors engineering, and vehicular technologies literature is aimed at exploring the inadequacies of the current SA evaluation methods.
The framework developed here combines physiological metrics, task-related performance metrics, and self-reported measures of AV testing to provide a comprehensive evaluation of SA in AV testing, considering its multi-dimensional aspects. It also shows the impact of age, training, and interface design on cognitive inertia. We aim to re-conceptualize the measurement and maintenance of situation awareness in new vehicle technologies by blending theoretical and empirical perspectives on the approach.

2.1 Theoretical Models of Situational Awareness

The most accepted model of situational awareness is based on Endsley's three levels which are: (1) perception of relevant elements in the environment, (2) understanding their relevance, and (3) forecasting the evolving situation. The model focuses on the cognitive elements of the situational awareness and decision making on performance in fast-paced, high-stakes environments such as autonomous vehicle (AV) testing. In real life, situational awareness is fluid and affected by internal (e.g., mental exhaustion) and external (e.g., the level of complexity of the interface) considerations. While Endsley's model is empirically robust, most studies implementing it relied on interviews or surveys as the main data collection method. These methods do not capture the real-time, within moment cognitive changes on the participant's awareness, hence the need for real-time quantifiable assessments of SA. In AV testing, which is characterized by rapid and unpredictable changes, the need to assess SA in real time is paramount. This is the theoretical gap we sought to address in our study, which integrates neurocognitive technologies to measure SA in real time within the context of high-tech vehicle testing.

2.2 Human Factors in Autonomous Vehicle Testing Environments

The growing AV intersection of human factors research demonstrates cognitive and perceptual demands in AV settings. Unlike traditional drivers, AV testing specialists are required to perform supervisory control functions like monitoring the system, verifying decisions, and engaging in override procedures. These functions require consistent focus and dynamic cognitive shift from being a passive watcher to an active (in) . Environmental complexity, encompassing variation in traffic, system-generated alerts, and multi-modal interfaces, can be stressful even for experienced testers [15]. Moreover, poor trust and in-built feedback mechanisms can decrease trust and situation awareness (SA) . Human factors engineers prescribe systems-error prevention through alignment of ergometric displays and feedback mechanisms. Most designs today focus on sol/systems efficiency instead of cognitive compatibility. This subheading aims to demonstrate human perception limits in supervision AV systems and why designed systems aviation on human thresholds of perception, attention, and rhythm of decision making. This is through the human perception limits in AV systems and why such systems should be designed focusing on human thresholds of perception, attention, and decision making based on recent findings. This is through the human perception limits in AV systems and why such systems should be designed focusing on human thresholds of perception, attention, and decision making based on recent findings.

3. RESEARCH METHODOLOGY

This mixed-method research assessment situational awareness (SA) for the designated workforce AV (autonomous vehicle) testers by tracking concurrent neurocognitive systems and their performance metrics alongside the post-task evaluation. This research was conducted inside a state-of-the-art driving simulator designed to replicate the working conditions of AV (autonomous vehicle) test engineers. The research is designed to assess the dynamics of SA for a given situation at multiple levels—action, physiology, and thought—along with the intra-subjects' factors of experience, stress, interface, and its familiarity. Participants underwent simulation of AV driving tasks at three levels of system complexity: low automation (full manual control), medium automation (subordinate to semi-autonomous systems with manual override), and high automation (autonomous operation with intervention only during critical system failures). Key dependent measure's reaction time, task performance accuracy, decision-making time, and system trust score fell under the independent task of interface complexity, task time, and cognitive load. Physiological measures were gathered with a headset that incorporates EEG, eye tracking, and HRV, thus enabling the assessment of cognitive workload and focus in the moment. Post-task subjective measures of workload (NASA-TLX) and situational awareness (SAGAT) were administered for corroboration. Findings were also triangulated with video and system log records, eye gaze heat maps.
This integrated approach explores the attention allocation, awareness maintenance, and lapsed monitoring involving AV testers under different automation levels. This approach, which utilizes biometric techniques alongside behavioral and self-reported data, creates a unified system capable of diagnosing cognitive and performance-related inflection points due to workflow and mental exertion. It also aids in creating customized instructional materials and interfaces based on the user's situational awareness (SA) capabilities.

3.1 Participant Selection and Testing Environment

Participants were selected from a group of professional AV testing engineers and vehicle operators with a minimum of two years of experience with semi-autonomous vehicle trials. A total of thirty individuals were selected for the sample, equally divided for age and gender, and further stratified based on past encounters with automated systems. A cognitive, ADAS familiarity, and stress resilience screening was conducted prior to the main evaluation. The evaluation setting was a driving simulator laboratory AV test which closely mirrors the procedural AV test settings. The simulator had real-time sensors, a driving dashboard, and scripted traffic stimuli which required manual overrides for human control. The degree of environmental complexity was controlled by adding system malfunctions, unpredictable road risks, and variable clarity and AV communication. This approach offered controlled estimation of the situational awareness and contextual load interactions. The testing space was designed to minimize external distractions and used controlled lighting and sound to eliminate background noise, avoiding confounding factors for the physiological recordings.

3.2 Tools and Metrics (EEG, Eye-Tracking, Driving Simulator, NASA-TLX)

Assessing situational awareness fully requires employing four key tools. EEG measures associated cognitive workload, especially during demanding periods, monitoring theta and beta wave activity. Eye-tracking feature assessed visual attention to discerning fixation duration, saccadic activity, and assisting in identifying attentional drift and tunnel vision.

The high-fidelity driving simulator posed structured scenarios with system alerts and required critical moment interventions, ideal for gauging reaction latency and decision evaluation. Participants also filled in the NASA Task Load Index (NASA-TLX) after every scenario to measure perceived workload in mental and physical demand, time, performance, effort, and frustration. These scores and their physiological indicators for validation in alignment were verified. The situational awareness (SA) capabilities and cognitive states of the participants were informed in real time, and through the use of these tools, the understanding gained was triangulated. Bridging internal cognitive processes and external performance benchmarks, this study aligns biometric and behavioral datasets.

4. RESULTS AND ANALYSIS

The investigation uncovered specific connections between situational awareness (SA) and both physiological and behavioral markers at each of the three levels of automation. During the manual supervision phases of the task, participants exhibited high accuracy along with consistent EEG beta activity suggestive of attentive engagement. Centralized eye-tracking fixations on critical system goals corresponded with prompt reactions and high SAGAT scores. With increasing levels of automation, signs of cognitive disengagement and attentional lapses became progressively stronger. In semi-autonomous conditions, participants demonstrated divided attention marked by shorter fixation durations and greater gaze dispersion. EEG readings showed increased theta activity associated with cognitive fatigue and reduced alertness. Though performance on the tasks remained satisfactory, subjective workload ratings on NASA-TLX for mental demand and frustration began increasing. This pointed towards the potential cognitive overload from the complexity of toggling between observation and control mode. In fully automated conditions, most participants exhibited a pronounced drop in readiness to respond. Their reaction times to system alerts became sluggish, accompanied by reduced heart rate variability (HRV)—a stress marker—and diminished eye fixation on danger zones. A number of participants were unable to notice system discrepancies during the simulation, demonstrating decreased SA.

Even with less manual engagement, perceived workload for effort and performance remained elevated. This supports the notion that the cognitive load resulting from the automation of tasks is not always beneficial; automation can lead to disengagement and worsen situation awareness (SA). The findings underscore the importance of control interfaces for adaptive automation that enhance operator vigilance and situational awareness even in over automated contexts.

4.1 Patterns of Situational Awareness Across Test Conditions

The shift from manual to fully automated systems showed a situational awareness (SA) anomaly. In manual modes, operators monitored environmental cues and system performance, leading to high efficiency and accurate self-assessments of SA. With increasing complexity of tasks in a semi-autonomous system, a shift in attention allocation to environmental cues also led to a reduction in hazard detection and a temporal delay in necessary override commands. In fully automated systems, a number of participants showed signs of "automation complacency"—over-trust and decreased cognitive vigilance. This was observable with theta dominant EEG patterns, slower reaction times, and a greater number of missed alerts. Although participants subjectively perceived lower physical effort, their mental effort scores remained high, indicating some form of disengagement relative to workload. These observations highlight the critical AV interface design challenge: the malleable trust and cognitive engagement required to retain effective situational awareness in the testing.

4.2 Cognitive and Physiological Correlates of Performance

Physiological and cognitive indicators operationalized situational awareness levels with predictive accuracy. In eye-tracking data, higher performers-maintained fixation on relevant dashboard and roadway hazard cues, while lower performing participants with less crucial fixation time demonstrated more erratic saccadic movements. EEG data showed higher theta power and lower beta activity associated with cognitive disengagement and lower situational awareness levels. During high system uncertainty, heart rate variability (HRV) notably decreased for most participants, indicating heightened stress and reduced stress response adaptability. Participants with experience in automated systems demonstrated more stable HRV profiles and override decision timing, while diverging from most automated system participants controlled chronometric efficiency. Poor situational awareness ratings were strongly correlated to low EEG frontal asymmetry, suggesting emotionally disengaged or frustrated. These findings highlight the importance of systems with real-time cognitive state assessment where feedback or alert interfaces can be adjusted to protect situational awareness under pressure.

5. INDUSTRIAL AND TRAINING IMPLICATIONS

The findings of this research study provide important insights for the industry concerning the efficiency and safety of professionals tasked with testing an autonomous vehicle (AV). The findings corroborate that situational awareness (SA) is an important aspect that can be overlooked during periods of high automation—especially during lulls when the automation does not demand any active participation due to poor system training. This emphasizes an industrial paradigm shift from reactive testing to proactive mental preparedness initiatives. From a system design perspective, AV developers need to incorporate, at a minimum, neurocognitive feedback loops within the testing environment. Continuous vigilance testing through EEG, HRV, and eye-tracking can provide preliminary indicators of waning engagement that can be corrected during the test by proactive system adjustments, feedback, or alerts. These safety monitoring systems can and should be standardized within AV tests to preserve cognitive engagement and prevent critical oversights. No less important is the need to implement training that focuses on cognitive flexibility, stress management, and attention management. Supervisors of autonomous systems require more than traditional driving instruction. Training should be tailored to the individual's performance trajectories and include edge-case simulations, accommodation adaptive exercises, and neurofeedback-assisted instruction. Above all, this emphasizes that leaders in the industry need to understand and accept that generic approaches will not lead to successful outcomes.

Training and interface optimization should align with the tester's neurocognitive profile, level of experience, and adaptability thresholds. Customization with this degree of specificity not only ensures safety and efficiency but also mitigates tester fatigue and chronic workplace stress. The organizational implications are striking: alongside the cognitive technology, safety and human resource investments are necessary to address the human factors design and the actual field human factors testing operations.

6. CONCLUSION

This research offers an in-depth exploration of the cognitive and physiological components of situational awareness (SA) in professionals involved in autonomous vehicle (AV) testing. By integrating neurocognitive measures of EEG, HRV, and eye-tracking with behavioral and subjective performance indicators, we have illuminated the dual nature role of automation in the enhancement and degradation of human situational awareness. The assumption that automation reduces mental workload is reversed in our findings, as higher levels of automation can lead to cognitive disengagement and sluggish response times to intervening—both of which endanger safety during testing. Participants who were more exposed to AV systems or cognitive-based training demonstrated better adaptive performance, attentional maintenance, and coping resilience during rigorous testing. This underscores the need for customized training interfaces and designs that are tailored to support cognitive demands. Additionally, real-time monitoring systems proved useful in detecting fatigue and attentional lapses, paving the way for proactive safety interventions. Industrially, this research promotes the need for human-centered testing frameworks, adjustable system support, and ethical data governance in AV processes. This study presented the need for human cognition to be safeguarded alongside the efficiency of automation in AV testing, serving as a foundation for developing AV testing strategies. Further research is needed on this foundation with diverse participant groups and real-world testing environments.
Furthermore, the implementation of adaptive interfaces powered by AI, as well as the continuous evaluation of cognitive health metrics within AV testers, could improve cognitive safety margins. With the progression of AV technologies, the measures taken to maintain human awareness need to parallel the developments made to ensure that autonomous systems are responsive to the cognitive frameworks of the human operators.

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